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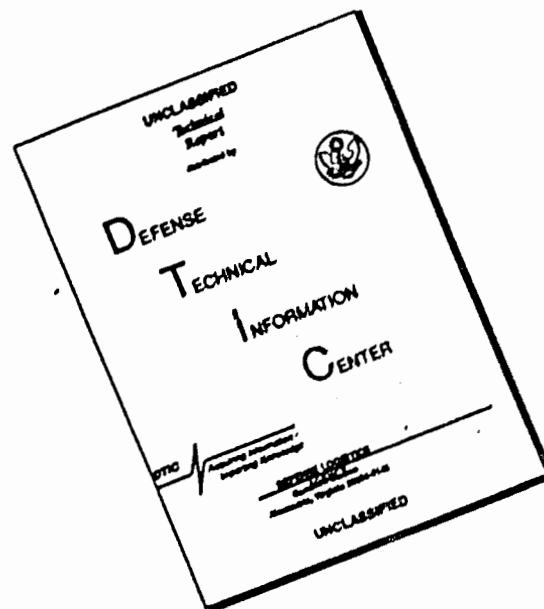
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SCIENTIFIC USE OF AN ARTIFICIAL SATELLITE

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Professor Sydney Chapman has given a description in Nature on August 22, 1953, and January 8, 1955, of the scientific efforts which are being made by some forty nations for the International Geophysical Year (IGY) to be held in 1957-58. Since the Special Committee for the IGY of the International Council of Scientific Unions at its meeting in Rome in September, 1954, recommended the use of a small earth-circling satellite vehicle for basic scientific observations, the problem has been brought closer to workers in various fields of science. The announcement of President Eisenhower on July 29, 1955, of plans in the U.S.A. for the construction of an earth satellite vehicle for use during the IGY was enthusiastically received by scientists all over the world.

The satellite project is programmed by the U. S. National Committee for the International Geophysical Year. The National Committee, whose members consist of scientists from universities and other learned institutions, has been appointed by the National Academy of Sciences of the United States. Financial support for the scientific program is

* Consultant to The RAND Corporation; member of the Institute of Geophysics, University of California, Los Angeles.

provided by Congress through the National Science Foundation as the appropriate Government agency for sponsoring basic research. The Department of Defense will give the necessary logistic support.

Some of the reasons for the universal interest in this project will be apparent from this paper, which gives a description of the more important observations which can be made from an artificial satellite, and discusses the useful application of these observations to scientific problems.

Apparatus used by scientists for observing from the ground the upper reaches of our atmosphere, our planetary system, and the galaxies have almost reached their upper limit for size and capacity because of the physical limitations induced by the ever-present atmosphere.

However, above the earth's atmosphere, at an altitude of 300 to 500 miles, the effect of the atmosphere is practically negligible. For example, Spitzer,⁽¹⁾ of the Department of Astronomy at Princeton, has calculated that a 40-inch telescope flown at 500 miles altitude could resolve objects that are only one-tenth as large as the smallest object which the 200-inch telescope operating from the ground can now resolve.

Now, the transportation of a 40-inch telescope to 500 miles above the earth's surface does not at present seem very feasible. However, there are many ways in which, on

the basis of our present-day knowledge and means, an artificial satellite could provide information not obtainable from any other source. Although the rocket research program has made great contributions to science, it may be said that rockets, because of their short stay at the required altitudes, have allowed us only a glimpse of the unknown, showing the tremendous possibilities inherent in a continuous observation station in outer space.

SOLAR RADIATION IN THE ULTRAVIOLET AND X-RAY REGION

A measurement of great potential value to various branches of science is that of the radiation in the ultraviolet and X-ray region of the spectrum reaching our atmosphere from the sun and its corona. At present, we have no clear knowledge of the intensity of this radiation due to the fact that virtually all of it is absorbed by the atmosphere. This very act of absorption produces reactions in our upper atmosphere that contribute substantially to the formation of the ionosphere, and therefore have a direct effect on radio communication. The effect of these reactions is propagated downward to lower levels and thus has an indirect effect on the weather of our planet.

An artificial satellite, able to measure over an extended period of time not only the radiation entering the atmosphere when the sun is quiet, but also the radiation emitted during solar flares and other solar disturbances, would be of vital help in the understanding of radio

blackouts and might provide a clue to the correlation of weather phenomena and specific solar activity. The continuous vertical shifting of the ionized layers with latitude, season, and time of day may be explainable from these observations, in which case better predictions for communication purposes could be made. Further, measurements of the unabsorbed radiation in this spectral region would help the astronomer improve his deduction of the densities and temperatures present in the photosphere, chromosphere, and corona.

The methods used to detect solar radiation in the atmosphere depend on the wavelength region of interest and on the altitude above the earth at which this radiation is observed. At an altitude of about 250 miles practically the entire spectrum of radiation emitted by the sun and its corona should be present, since the air density is so low that only a small amount of the radiation could have been absorbed.

Ultraviolet radiation in the interval between 2000 Å and 3800 Å can be detected by spectrographs.⁽²⁾ Below 2000 Å the presence of ultraviolet and X-ray radiation can be detected by means of a thermoluminescent phosphor, $\text{CaSO}_4:\text{Mn}$, which has the property of being sensitive to wavelengths below, but not above, 1340 Å.⁽³⁾ The excitation energy stored by the phosphor can be released by heating and measured by means of a photomultiplier; thus the response gives a measure of the ultraviolet radiation to which the phosphor was exposed.

X-ray and extreme ultraviolet radiation can also be measured by photon counters.⁽⁴⁾ A V-2 rocket, fired in September, 1949, carried a set of photon-counter tubes which were sensitive to radiation in the soft X-ray and extreme ultraviolet region. Each tube in such a set responds to a narrow portion of the spectral region in one of the four bands covering 0 - 10 Å, 1100 - 1350 Å, 1425 - 1650 Å, and 1725 - 2100 Å.

"Day airglow" light in the visible region of the spectrum at great altitudes can also be observed by means of radiation detectors provided with proper filters. Rocket-borne equipment has been used for airglow observations in the experiments conducted by Miley.⁽⁵⁾ The information was telemetered to the ground, along with rocket orientation data.

ELECTRON DENSITY MEASUREMENTS

Measurements of electron densities and their continuous variation with time and height play an important part in the study of radar and communication problems. The effective frequency of collisions between neutral and ionized particles in the atmosphere, which can be taken as a measure of the attenuation of radio waves, can be deduced from electron densities, if the neutral particle density and the effective collision cross-sections are known. Electron densities are related to the total number of ions produced by the radiation from the sun and its atmosphere and also to the effective recombination coefficient, which determines the rate at which ions and electrons recombine to form neutral atoms. All of

this information is needed by the upper-air physicist to advance our knowledge of the ionosphere and by the astronomer to advance our picture of the sun.

The determination of electron densities in the ionosphere (the region between 70 km and 300 to 400 km) is essentially based upon the electromagnetic wave propagation theory. The Appleton-Hartree formula^(6,7) gives a relationship between the index of refraction of the ionosphere and the free electron density, the relationship being a function of the frequency of the electromagnetic wave. By sending two pulses, one at such a high frequency that it has an index of refraction of essentially unity throughout the ionosphere, and the other at a frequency well above the critical frequency, and by measuring the difference in time of travel to the ground of the two pulses, it might be possible to get a measure of the total electron density along the path.

Seddon⁽⁸⁾ from the Naval Research Laboratory in Washington, D. C. has successfully used a CW-frequency system with rockets. By sending a low frequency and its multiple (say, six times the low frequency) from the rocket to the ground, and observing the shift in frequency of the original low one at its time of arrival, one obtains the index of refraction along the path. From the continuous variation of the refraction index with altitude, the continuous variation of electron density with altitude can be deduced.

A satellite with the simple two-pulse system or a CW-frequency system can give a broad-scale and continuous picture

of the total electron density or "thickness" of the ionosphere, a picture which at present can only be estimated by means of signals sent up from the ground and reflected from the ionospheric layers. Recent experimental results attained by means of rockets indicate a large discrepancy between the true height of these ionized layers and the apparent height deduced from observations made from the ground.

Difficulties in interpreting the data may arise because of the oblique arrival of the signals from the satellite as it approaches or recedes from an observing station. These difficulties can be avoided with sounding rockets.

PRESSURE, DENSITY AND COMPOSITION MEASUREMENTS

The thermodynamic state of the atmosphere is determined by a knowledge of the distribution of pressure, density, mean molecular weight and temperature with altitude. It is not possible to measure directly the temperature of a gas as tenuous as the atmosphere at 250 miles, so that attention must be focused on the other three parameters. Of these three, the most difficult is probably the composition which leads to the determination of the mean molecular weight.

Mass spectrometers have been used in rocket research and can be carried in an artificial satellite. With the help of these instruments it is possible to observe the mass number of the ionized particles and their relative abundance, though such an experiment at the altitude of a satellite would require a considerable extension of current techniques, particularly because of the large mean free path of the air particles at

these altitudes and the weight of presently available equipment.

Given the composition, either by measurement or deduced from theoretical considerations, the remaining variables necessary to specify the thermodynamic state are the pressure and density.

The pressure of the atmosphere has been measured directly up to about 100 km by gauges sensitive to pressure as low as 10^{-6} mm Hg.⁽⁹⁾ However, pressure gauges of higher sensitivity (approximately 10^{-10} mm Hg) are under development and might be used on a satellite vehicle to measure the low pressure that has been estimated to prevail at greater heights.

Above 100 km, ram pressure, caused by the extremely high speed of the vehicle, has been measured at the nose of a rocket, and the densities have been derived from these measurements. The greater speed of the satellite, which would create ram pressures several orders of magnitude higher than the ambient pressure, would be of advantage in pressure measurements as well as in mass spectroscopy.

A relatively simple experiment which might pay great dividends is the discharge of a large-volume, low-mass spherical body, say a balloon, possibly made of metal foil, from the satellite. The drag force on such a body, small as it might be, would be large compared to the drag force on the satellite. If such a body were to be towed for a few revolutions, the tension on the tow line would be a measure of the differential drag and could be telemetered to the earth to provide data on

air density. If the body were then cut free from the satellite, the differential drift of the balloon from the body, as observed from the earth, would provide measurements of the air drifts at these extreme altitudes.

After the balloon is freed from the satellite it would be subjected to the motions of the atmosphere, and the perturbations of the balloon's orbit would permit estimates of the mass movement of the atmosphere.

One of the attractive features of ejecting a balloon from the satellite is the fact that much information could be obtained without any telemetering. The comparison of the orbit of one small, heavy satellite with another large, light satellite in the form of a balloon, as determined from ground observations alone, would provide direct evidence of atmospheric drag effects at the orbit altitude.

COSMIC RAYS

Ever since cosmic rays were discovered some forty years ago, questions associated with the nature and origin of this radiation have been among the most intriguing in physics. An answer to these questions might give a knowledge of the highest voltage generative force in the universe, and perhaps even a better insight into the ancient question of the origin of the universe. A study of the behavior of primary cosmic ray particles would also further our understanding of the fundamental forces which bind sub-atomic particles.

Rocket instrumentation has yielded sporadic observations of primary cosmic rays;⁽¹⁰⁾ an artificial satellite at great altitudes making prolonged observations would be the ideal research tool in this field because it has the ability to rapidly survey the intensity distribution of incoming primaries, and consequently the effect on them of the earth's magnetic field. Time variations of cosmic ray intensity can be sensed from such a satellite, an observation which would have an important application in studies of the correlations between solar and geomagnetic activity.

Observations of heavy primary particles such as protons, alpha-particles, and heavier nuclei are made by means of cloud chambers, ionisation chambers, Geiger counters, Geiger telescopes, and photographic emulsions (the latter requiring physical recovery of the film).

THE ALBEDO OF THE EARTH

To date, reflection of sunlight by the earth has been calculated from estimates of the reflection from clouds, oceans, snow fields, forests, etc.,⁽¹¹⁾ or by the earthshine reflected from the dark side of the moon.⁽¹²⁾ These techniques, useful as they are, have serious limitations, as discussed by Frits.⁽¹¹⁾ A satellite vehicle would have an unobstructed view of the earth and sky, so that the radiation reaching the earth from the sun and the radiation reflected from the earth back into space could be measured.

The measurements taken from a bolometer pointing toward the sun would provide a direct determination of the so-called

solar constant, and possibly information as to its variation. The measurement of the incoming energy, the reflected⁽¹³⁾ and back-scattered energy, and the outgoing long-wave radiation would provide the necessary energy data for studies of the thermodynamic state of the earth and its atmosphere. An accurate knowledge of the energy balance of the earth-atmosphere system for even a short period would do much to advance our knowledge of the energy conversion mechanism of the earth-atmosphere system.

OBSERVATION OF METEORS

Meteors are observed from the ground by the visible light and ionization they cause when entering the earth's atmosphere. High-speed telescope cameras and radar equipment are used for observing these effects.^(14,15,16) The brightness of an individual meteor is determined by comparison with a standard brightness--that of the sun or a star. The brightness is measured in terms of stellar magnitudes. For example, the sun has a magnitude of -27.7, the full moon of -12, and Venus, at its brightest, of -4. The radar signals sent up from the ground are reflected from the ionization trail of the meteor or from the cloud of electrons around the large meteoroids.⁽¹⁷⁾

It is obvious that enormous difficulties are encountered in determining the number, masses, and densities of meteors entering the earth's atmosphere per day, on the basis of these rather limited observations. Telescope cameras cover only a small region of the sky at a time, and also are limited as to the order of magnitude to which they can see. Radar observations are

hampered by the fact that for small particles their path must be perpendicular to the beam; otherwise no signal will be returned.

Several pieces of information are missing in in the study of meteors which would greatly advance this particular phase of scientific endeavor. First, from a determination of the total number of particles which impinge on an artificial satellite of a known exposed area during a known time interval, the total amount of dust entering the atmosphere could be calculated. There is recent evidence that more dust enters our atmosphere than we have so far assumed. The old question may be answered of how much, if any, of the dust causing the zodiacal light effect drifts down to us. Observations made by the satellite during the time of known meteor shower occurrence would be helpful. Information on velocity and direction of particles, if it could be deduced from impact measurements, would add greatly to our knowledge of these showers.

There is a more or less permanent component of the E-layer, present at night as well as during the day, which has recently been exploited for VHF radio propagation. Part of this component is probably due largely to meteor ionisation, though there is some question about the mechanism and the number of meteors which are involved. Actual observations of meteors in the small size range would improve our understanding of the phenomena in this important new field of radio communication.

The impact of meteorites and micrometeorites on the skin of an artificial satellite can be measured by means of microphones.

The method of detection developed at Temple University⁽¹⁸⁾ for rocket experiments is to use a tuned amplifier and a crystal microphone having a peak response at the same frequency as that of the tuned amplifier. The information can be telemetered. The number of pips observed in the telemetered record would give the number of dust particles encountered by a known area over a known period of time. Some orientation information would be required.

A more elaborate experiment could be devised which would give data on size and penetration of meteoroids. For example, if a succession of diaphragms, each of which would act like a microphone, were exposed to a swarm of small meteors, the front diaphragm would record all impacts. At the same time, it would be pierced by the meteoroids with higher energy. The next diaphragm would record these, and would in turn be pierced by the more penetrating ones. Depending on the arrangement, one could obtain a rough frequency distribution of the penetration characteristics of meteors over a range of penetration thicknesses. This scheme is presented merely to show what might be done. The data obtained by this method would be extremely valuable in the interpretation of meteor studies.

Other types of information concerning meteors can be obtained by use of a scientific satellite. Artificial meteorites can be ejected from the vehicle by means of shaped charges. It has been suggested that a 10-lb charge will produce a spray of small particles of various sizes which will move with velocities comparable to the velocity of meteors entering the earth's

atmosphere from outer space. As these artificial meteors enter the denser portion of the atmosphere, they will produce visible light and ionization between 100 and 200 km, depending upon their size and the density of the material used. The visible radiation and the ionization can be observed from the ground. It should be added, however, that such an experiment could probably also be done by a sounding rocket which attained velocities and altitudes similar to those of the satellite.

MEASUREMENT OF THE EARTH'S MAGNETIC FIELD

Two obviously important applications of magnetic field measurements concern studies of cosmic rays and studies of the interactions between magnetic disturbances and the conditions in the ionosphere. Since the earth's magnetic field has an influence on moving charged particles, it is clear that it influences incoming protons, alpha particles, and possibly electrons, which make up the primary cosmic rays.

Moreover, there are very significant variations in this field due to complicated interactions between the motions of charges in the upper atmosphere and the geomagnetic field itself. It has frequently been pointed out that the winds in the ionosphere, which carry charged particles across the magnetic lines of force, make the ionosphere behave like an electric generator. (19,20,21) The currents which are generated then produce magnetic fields, which are measured at the earth's surface as perturbations on the steady field. These perturbations become particularly noticeable during "magnetic storms," and may amount to as much as 10 per cent of the permanent component.

The distribution of these electric currents and wind systems is only partially understood, and it is certain that much could be learned about them from high-altitude magnetic observations. In fact, the existence of a "current sheet" between 80 and 90 km near the geomagnetic equator has already been demonstrated by such a technique with a sounding rocket.⁽¹⁹⁾ It would probably be particularly useful to follow the whole course of a magnetic storm from the altitude of a satellite.

A rocket-borne total field magnetometer has been developed and used by Maple, Bowen and Singer;⁽¹⁹⁾ and by Fraser.⁽²²⁾ This device is independent of the orientation of the vehicle. The new Varian nuclear resonance magnetometer is designed to give good accuracy with less weight. The Varian device has not yet been tested in rockets. Either of these devices could conceivably provide telemetered data on the earth's magnetic field at the location of the satellite.

ARTIFICIAL SEEDING OF THE ATMOSPHERE

For better or worse, it has always been man's desire to copy nature. Nature is being copied in the laboratory all the time; however, the chemical laboratory has not yet been extended into outer space. Many of the implications of artificial seeding conducted in the free air in an unbounded chamber and under conditions of pressure unattainable in the laboratory have been pointed out by J. Kaplan, of the University of California, Los Angeles. Since rockets have become available as research tools, artificial seeding, i.e., the spraying of material into the atmosphere at high altitudes, has been made possible.

The reasons for the great interest in this new area of research are manifold. Chemical and photochemical reactions which occur at high altitudes are the backbone of all theoretical research of the upper atmosphere, which tries to explain and eventually to predict the observed phenomena. These reactions, which change not only with altitude but also with the time of day, the seasons, and latitude are complex, and relatively little is known about them. Based on knowledge and great ingenuity, acceptable explanations for some of the observed phenomena have been made in the past.^(23,24) Certain experiments performed under specified conditions and observed from the ground would further our knowledge in this field.

For example, in 1950 David Bates of the University of Belfast submitted a proposal to the Rocket Panel⁽²⁵⁾ suggesting the artificial altering of the amount of atomic sodium in the upper atmosphere. It is a well-known fact that a part of the twilight and the light of the night sky is produced by sodium atoms emitting radiation in the visible region of the spectrum. Sodium has a low excitation potential and emits light in the visible region of the spectrum which can be observed from the ground. Nature has provided us with sodium atoms in outer space from unknown sources. From a high-altitude vehicle we could add a few more of these atoms and determine the concentration necessary to produce the observed effects. In fact, the first experiment of this type has been performed very recently from a sounding rocket, and visible light has been observed (unpublished Rocket Panel Report).

GEODETIC MEASUREMENTS

Although the most obvious uses of the satellite vehicle are those connected with exploring the upper atmosphere and the space beyond, a very important function would also be to assist in determination of the shape, size, and constitution of the earth itself. These last determinations would require no telemetering of data from the satellite; the only requirement would be to track the satellite with great accuracy.

An improvement of our knowledge of the shape and size of the earth has been the goal of international geodesy for many years. More precise knowledge of the gravitational field of the earth would permit us to determine more accurately the distribution of mass in the earth's core and might help indirectly to answer problems having to do with the structure of the earth, the viscosity of the core, etc. These extremely complex problems will always intrigue geophysicists, since they are so basic to a knowledge of the origin of continents, the earth's magnetic field, the behavior of the earth's crust, the flux of internal heat, etc.

A great deal of our knowledge about the density of the earth's core and about the dimensions of the earth is derived from careful astronomical observations of the disturbance of the moon's motion. Specifically, there are three effects of the earth's asymmetry on the moon:⁽²⁶⁾ a monthly perturbation of the moon's latitude, a steady advance of the perigee, and a steady recession of the node. The last two were discovered only

recently, because they are partly masked by the much larger effects of the sun's gravity. In addition to these disturbances, the time of transit of the moon over various points on the earth gives a measure of the distances between these points (provided we can know some of the other dimensions very accurately). In this way, for example, one can estimate the distance between continents, where it is obviously impossible to extend a conventional geodetic survey.

An artificial satellite, if it could be seen clearly during the twilight period, would have several advantages over our natural satellite. It is smaller, and so measurements of its position can be much more precise; it is closer to the earth, which means that its motion will be more affected by the earth than by the sun's gravitational force; it travels around the world faster, so that one can get more observations in a given time; and the fact that its orbit can be tipped more with respect to the equatorial plane will result in a larger perturbation of its motion, which will give more precise data on the earth's asymmetry.

Established observatories now spotted over the globe would offer ideal sites for these observations. They would have to install new equipment or modify their telescopes to track the rapidly moving satellite, and this would require a considerable redesign of the driving mechanisms. In other respects the problems associated with this kind of observation are familiar to astronomers.

COSMIC AND SOLAR HIGH-FREQUENCY RADIO NOISE

The use of "radio telescopes" has in a short time added greatly to our knowledge of the universe and the structure of the sun. The radio spectrum is in many ways more useful than the visible spectrum for astronomical studies. However, the ionospheric cutoff of electromagnetic waves of frequency below 5 Mc is tantalizing to the radio astronomers. Many studies cannot be completed until the spectrum of cosmic radio noise can be extended down into the high-frequency, and even low-frequency, part of the radio spectrum. To cite one case in point, it has been suggested that the sun emits radio waves at a very low (audio) frequency, with wavelengths corresponding to the dimensions of the sun itself. Although there are several serious objections to this suggestion, such as the fact that the "classical" magneto-ionic theory predicts that these waves cannot be propagated through interplanetary space, there are still some phenomena which suggest that these radiations may exist. The work of astronomers and ionospheric physicists will profit greatly from a look behind the "ion-curtain" of the F_2 -layer at the radiations which lie beyond.

Receivers and antennas which could be sent aloft on a satellite to measure the high-frequency and low-frequency spectrum below 5 Mc would be relatively easy to design. The antenna, for example, could be a whip antenna, extended after the vehicle was on orbit, and would be matched to the vehicle itself (presumably a conductor), so that it would have a reasonably high gain. If the antenna were very long, there

would be a possibility of direction-finding by noting a signal null as the vehicle rotated. The weight of equipment necessary to extend such an antenna is prohibitive, at present; nevertheless, by such a technique, provided there were orientation information, one could determine whether the source of radio emission was the sun or some "cosmic" source. In the case of low-frequency signals, diffraction around the earth would supply directional information.

The actual frequencies selected for study should cover as wide a range as possible. Individual frequencies could be received simultaneously and sorted out on the ground by a harmonic analysis, or the satellite receivers could be tuned or switched in frequency.

GENERAL CONCLUSIONS

The foregoing has been necessarily a brief summary of the general areas of study which are about to be opened up with the advent of the first artificial satellite. The possibilities for growth in this field are unlimited, and man is entering an era in which new ideas, new techniques, and new discoveries will help to advance his knowledge in many different fields of science. The first satellite will probably be fairly limited in payload and performance, and the observations may be meager, but it will be a milestone in technical development for the advancement of science.

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